COMPREHENSIVE REVIEW

Intraosseous Access in the Prehospital Setting: Literature Review

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Abbreviations:
BIG: bone injection gun
EZ-IO: semiautomatic intraosseous infusion system
FAST-1: semiautomatic intraosseous infusion system
IO: intraosseous
IV: intravenous
MAN-IO: manual intraosseous device

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Abstract

Background: Although the majority of Australian intensive care paramedics use the manual intraosseous infusion technique (MAN-IO), several other semiautomatic devices now are available, such as the bone injection gun (BIG) and the semiautomatic intraosseous infusion system (EZ-IO). Given the choice of devices now available, questions have been raised regarding success rates, accuracy, decay of skills, and adverse events.

Objectives: Review the literature regarding the use of intraosseous (IO) devices in the prehospital setting.

Methods: Selected electronic databases (Medline, Embase, and CINAHL) were searched, and a hand search was conducted for grey-literature that included studies from the commencement of the process to the end of May 2010. Inclusion criteria were any study reporting intraosseous insertion and/or infusion (adult and pediatric) by paramedics in the prehospital setting.

Findings: The search located 2,100 articles; 20 articles met the inclusion criteria. The review also noted that use of IO access (regardless of technique) offers a safe and simple method for gaining access to the patients' vascular system. A number of studies found that the use of semiautomatic devices offers better and faster intraosseous access compared with the use of manual devices, and also were associated with fewer complications. The findings also suggest that the use of semiautomatic devices can reduce insertion times and the number of insertion attempts when contrasted with the use of manual insertion techniques. Despite these findings, statistically no specific IO device has proven clinical superiority.

Conclusion: While manual IO techniques currently are used by the majority of Australian paramedics, the currently available evidence suggests that semiautomatic devices are more effective. Further research, including cost-benefit analyses, is required at a national level to examine skill acquisition, adverse effects, and whether comparative devices offer clinically significant advantages.

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Introduction

Gaining vascular access in patients in the prehospital environment often is crucial and challenging. In the circumstance in which an intravenous (IV) access is delayed or not obtainable, an alternative site is required, and often may be achieved using an intraosseous (IO) device. While IO infusions traditionally have been used in pediatric patients, the frequency of use in adults is growing.[1] Since Drinker et al first proposed the technique 90 years ago,[2] interest has been overshadowed by the development of the IV route.[1,3] The Australian Resuscitation Council recognizes that while IV access is the first line choice, it should be attempted for no longer than 90 seconds during the management of a victim of cardiac arrest.[4] If unsuccessful, an IO insertion is recommended as both a safe and necessary substitute.[4] Similar approaches to difficult vascular access have been suggested by Gazin et al,[5] who proposed that only two peripheral venous attempts be made before attempting IO insertion in cardiac arrest victims.

Currently in Australia, only intensive care paramedics have authorization to insert an IO needle. The majority of these paramedics use the manual intraosseous infusion technique (MAN-IO) using the Cook needle (Cook Med. Inc., Bloomington, Indiana USA). Other manual IO needles that are available include the Jamshidi (Cardinal Health, McGaw Park, Illinois USA) and the Sur-Fast (Cook Critical Care, Bloomington, Indiana USA) needles.

The more recently evolved semiautomatic devices, such as the FAST-1 (Pyng Medical Corporation, Richmond, British Columbia, Canada); the EZ-IO (Vidacare, Shavano Park, Texas USA); and the Bone Injection Gun, BIG (Waismed Ltd., West Hempstead, New York USA), are used by some flight paramedics. Current literature suggests that there is a move toward the use of semiautomatic devices in other prehospital settings throughout the world.[6,7] While this paper focuses on the Australian paramedic system, the current trends suggest that this review of the IO literature has application and relevancy for paramedic systems beyond Australia.

The availability of a variety of IO devices requires that the Australian paramedic sector respond to the rapidly changing technologies based on sound evidence-based research. Moreover, the findings from empirical research should form the platform for a cost-benefit analysis, and assist in determining whether the currently used manual technique should be replaced with the use of the more contemporary semiautomatic intraosseous devices. While a body of knowledge exists on user satisfaction with the various IO devices, less literature is available on the direct clinical benefits associated with the use of IO infusions. To the authors' knowledge, no prehospital-based research has been undertaken examining IO insertion success rates or clinical outcomes in Australia. The purpose of this paper is to review the literature on IO insertion in the prehospital setting.

Methods

A comprehensive search strategy was conducted to include both peer-reviewed and non-peer-reviewed literature. A prehospital search filter initially developed by the Cochrane prehospital field [8] (Table 1) was used to search the following electronic databases for articles published during the dates indicated: Medline (US National Library of Medicine, Bethesda, Maryland USA), 1950 to the end of May 2010; Embase (Elsevier B.V., Amsterdam, The Netherlands), 1974 to the end of May 2010; and CINAHL (EBSCO Publishing, Ipswich, Massachusetts USA), 1986 to the end of May 2010. The following medical subject heading (MeSH) terms in the US National Library of Medicine index were used: "infusion," "intraosseous," "IO," "vascular access," "bone injection," and "devices." In addition, a manual search of relevant grey-literature was performed.

The inclusion criteria consisted of any published studies in the prehospital environment or relating to paramedics reporting intraosseous insertion and/or infusion in both adult and pediatric patients. Studies involving animals were included if they related the findings to in-field practice on humans. Non-English papers were excluded.

emergency medical service$.sh
emergency medical technic$.sh
ambulance$.sh
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or/1-16
limit 17 to (human and English language)
18 not (letter or editorial).pt

Table 1. Filter Used in Search Strategy

Results

A total of 2,100 articles were identified. Following the elimination of duplicates and a review and critique of each article, a total of 20 papers met the inclusion criteria. Table 2 describes the study types, sample sizes, findings, and study limitations.

Semiautomatic Intraosseous Devices

EZ-IO—The device was independently examined in three separate studies[9-11] involving a combined total of 114 insertions in patients,[9,10] and 297 insertions in cadavers.[11] Each of these studies reported high insertion success rates (range: 94.0 to 97.3%).[9-11] Complication rates associated with the use of the EZ-IO device included infiltrations, slow flow rates, and needle dislodgment.[9] Horton et al reported a 6% rate of insertion failures and a patient complication rate of 4% with use of the EZ-IO device.[10]

User satisfaction with the EZ-IO was high, with the majority of users reporting that they felt comfortable or very comfortable with the device.[9] Reported insertion times varied among the three studies. Frascone et al[9] reported that the time required for insertion of the EZ-IO was <60 seconds in 72% of the insertions, although these data were obtained retrospectively via telephone interviews. Horton et al[10] reported insertion times of <10 seconds in 77.2% of the insertions, although the time interval measured only the time from skin contact to proper insertion of the needle. Levitan et al[11] reported an average insertion time of six seconds as measured from the time of skin contact until the stylet was removed.

FAST-1—This intraosseous device was investigated in three studies[7,12,13] involving nine in-field insertions and 39 scenario-based insertions. Miller et al[13] reported a 55% success rate of first insertion attempts, while Macnab et al[12] reported an 84% insertion success rate among first-time users, and a 95% success rate among experienced practitioners. The data regarding complication rates in each of these studies was not clearly articulated, or not examined.

Bone Injection Gun—Three studies have evaluated the use of the bone injection gun (BIG) with 229 insertions in living humans, and 13 insertions in cadavers.[14-16] Overall, the insertion success rate in adults ranged from 73.0 to 92.3%.[14-16] Insertion of the BIG device in children was successful in 73% of reported attempts.[14] The complication rates associated with insertion using this device ranged from 7% to 27% and consisted of issues

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Reference	Year	Device	Population	n	Insertion Time Mean (Range)	Success Rate (%)	Complications (%)
Studies Comparing Two or More Devices							
Hartholt[25]	2010	Jamshidi	Adult (>14 y)	65	37 (IQR 30-49) s	91.7	12.5
		BIG			49 (IQR 33-60) s	59.1	40.9
		FAST-1			62 (IQR 50-131) s	89.5	26.3
Hartholt[25]	2010	Jamshidi	Peds	22	43 (IQR 33-79) s	100.0	0.0
		BIG			48 (IQR 28-65) s	70.0	30.0
		FAST-1					
Brenner[27]	2008	MAN-IO	Cadavers	84	33, SD = 28 s	79.5	15.4
		EZ-IO			32, SD = 11 s	97.8	0.0
Frascone[26]	2007	FAST-1	Adults (>18 y)	89	N/A	72.0	44.0
		EZ-IO		89		87.0	18.0
Studies Individually Assessing the MAN-IO							
Anderson[17]	1994	Cook	Peds	15	N/A	87.0	6.7
Fiorito[18]	2005	Cook, Baxter, Monojet	Peds	47	N/A	78.0	12.0
Glaeser[19]	1993	Jamshidi	All ages (0-102 y)	152	N/A	76.0	12.0
Miner[20]	1989	Jamshidi	Peds (<2 y)	12	N/A	83.3	None observed
Pfister[21]	2008	Cook	Peds and adults	30	N/A	83.0	16.6
Seigler[22]	1997	Jamshidi	Peds	104	N/A	79.8	4.8
Seigler[23]	1989	Jamshidi	Peds	17	13 out of 17 within 1 min	94.0	None observed
Smith[24]	1988	Jamshidi	Peds	13	<30 s in all attempts	80.0	20.0
Studies Individually Assessing the EZ-IO							
Frascone[9]	2009	EZ-IO	Peds (<15 y)	19	72% <60 s	95.0	26.3
Horton[10]	2008	EZ-IO	<18 years	95	77.2% <10 s	94.0	4.2
Levitan[11]	2009	EZ-IO	cadavers	297	Median 6 s (range 3-25)	97.3	N/A
Studies Individually Assessing the FAST-1							
Findlay[7]	2006	FAST-1	Manikin	30	92 s (range 52-127)	NA	N/A
Macnab[12]	2000	FAST-1	Adults	29[a]	77 s (range N/A)	84.0	30.0
Miller[13]	2005	FAST-1	Manikin	29	27.5 s (95% CI 24-31)	93.1	N/A
Studies Individually Assessing the BIG							
Gerritse[14]	2009	BIG	Adult	40	N/A	73.0	27.5
			Peds			71.0	
Hubble[16]	2001	SV[b] cutdown	Cadavers	13	7.6 min, SD = 1.80	69.2	30.8
		BIG			3.9 min, SD = 0.82	92.3	7.7
Schwartz[15]	2008	BIG	All ages (2 wk-100 y)	189	N/A	91.0	9.0

Table 2. Studies Referenced in Analyses

Abbreviations: BIG, bone injection gun; EZ-IO, semiautomatic intraosseous infusion system; FAST-1, semiautomatic intraosseous infusion system; IQR, interquartile range; MAN-IO, manual intraosseous device; peds, pediatrics; s, second(s); y, year(s).

[a]Out of hospital.

[b]Saphenous vein.

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with the device and operator failures. The issues with the device were needle not firing, needle not securely placed, no flow achieved, and bone but not marrow entered. The operator issues identified were failure to remove the trochar needle after successful insertion, misidentifying bony landmarks, and missing the bone altogether. Additionally studies reported extravasation as a complication.[14-16] In terms of user satisfaction, Gerritse et al[14] reported that 80% of respondents deemed the use of the BIG device to be "very satisfactory." Inexperienced paramedic students gave the use of the BIG a procedure score of 96.2 out of a possible 100, although it is unclear if the rating scale demonstrated appropriate psychometric properties.[16]

The average insertion time of the BIG device was 3.9 minutes, which was the time to fluid flow in the cadaver model study.[16]

Manual Intraosseous Devices

Eight independent studies evaluated the use of manual intraosseous devices (MAN-IO), mainly investigating the Cook or the Jamshidi. One study[18] compared the Baxter IO needle (Baxter Healthcare Corporation, Deerfield, Illinois USA) and the Monoject IO needle (Sherwood Medical Company, St. Louis, Missouri USA) in a total of 400 insertions.[17-24] The reported insertion success rates in these studies ranged from 76 to 94%.[17-24] Glaeser et al[19] reported the insertion success rate to be higher in pediatric patients <3 years of age compared with older children. Infiltration and local edema were the most commonly reported complications occurring in up to 13% of the manual insertions.[17-20,22,24] Other reported complications can be classified as device- or operator-specific. Issues with the needle were dislodgement and bending, while operator issues again pertained to wrong location and failure to adhere to landmarks. Additionally, hematoma and fluid leak were reported.

In terms of user satisfaction, Smith et al[24] reported that 10 out of 11 operators scored the Jamshidi manual intraosseous device as "excellent" regarding its ease of use; the other studies did not assess this variable. The measurement of insertion times of the manual intraosseous devices was not reported in any of the studies, with the exception of the study by Seigler.[22] He reports the insertion time to be less than one minute in between 47% and 76% of attempts.[22,23] Conversely, between 17% and 23% took more than three minutes or required initiation of another bone marrow site. Smith et al[24] estimated all IO insertions to be less than 30 seconds.

Comparisons of Intraosseous Devices

There were three papers comparing different devices within the same study.[25-27] Hartholt et al[25] compared the Jamshidi 45G, the BIG 15G and the FAST-1. The Jamshidi was successful in 91.7% and the FAST-1 in 89.5% of attempts. This differed significantly ($P = .010$) from the low success with the BIG 15G (59.1%). Regarding the pediatric population, only the Jamshidi 15G and the BIG 18G were compared. The Jamshidi was successful in 100% of its 12 attempts, while the BIG 18G was successful in seven out of 10 patients. This difference was not statistically significant. They also reported that insertion of the semiautomatic FAST-1 and the Jamshidi IO needle was successful in 90% of attempts, compared with a 59% insertion success rate of the semiautomatic BIG device ($P = .010$). Regarding pediatric patients in particular, no statistically significant difference was detected, although there was a trend toward the manual Jamshidi being superior.

Frascone et al[26] compared the use of the semiautomatic EZ-IO device with the semiautomatic FAST-1 IO device and found the successful insertion rates to be 72% and 87%, respectively ($P = .009$). In a study comparing the semiautomatic EZ-IO device with the MAN-IO technique, Brenner et al[27] reported first attempt success rates of 97.8% and 79.5%, respectively, ($P < .01$), and failure to obtain access rates of 0% and 12.8%, respectively, ($P < .02$). The same study also found complication rates to be more frequent with the use of the MAN-IO technique compared with the semiautomatic EZ-IO device (15.4% vs. 0%, respectively; $P < .01$).

Hartholt et al[25] and Frascone et al[26] concluded that the differences in user satisfaction between the MAN-IO and semiautomatic EZ-IO device were insignificant statistically ($P = .52$ and .13 respectively) while Brenner et al[27] reported the EZ-IO to be preferable to the MAN-IO method (1.9 vs. 1.2 on a scale from 1 to 6; $P < .01$) in their randomized, prospective trial. The average insertion times for both devices were identical.[27]

In a comparison of the MAN-IO and the FAST-1, accurate placement was achieved more quickly with the use of the Jamshidi needle, 37 (P_{25}- P_{75} = 30-49) vs. 62 (P_{25}- P_{75} = 50-131) seconds, respectively ($P = .002$).[25]

Discussion

Due to the nature of situations requiring an IO insertion, prospective, in-field research is ethically and clinically challenging. Consequently, investigations have been conducted in animals[28-30] and classroom-based experiments,[31,32] which limit the ability to generalize the findings of the studies reviewed. Another confounding factor is related to the variations in sample sizes, design, and definitions of outcome measures. There are some limitations across all of the 20 papers included in this study. Several of the studies did not include unpacking, set-up, and preparation time when calculating device insertion times. This may have contributed to some of the reported contrasting findings regarding insertion times. It would seem logical that measuring variables, such as insertion times, should reflect real-time practice.

Several of the studies of IO use in real-life situations relied on retrospective questionnaires to assess outcomes, thereby diminishing the accuracy and external validity of the results. Moreover, due to the infrequent utilization of IO device insertions, most sample sizes are restricted, and subsequently lead to statistically insignificant findings. A further confounder is that some IO devices are utilized for the administration of fluids only, while others are utilized for the administration of drugs. Although some studies included other interesting components related to IO device insertion (i.e., ease of teaching, and skill acquisition and decay), the data provided are too sparse to draw conclusions. However, they do provide a good platform for future research projects, as evidenced in the recent work by Byars et al.[6]

Overall, the paucity of research relating to the FAST-1 device, plus the biasing role some authors hold as both researchers and company shareholders, emphasize the difficulty in generalizing the findings more broadly; a greater examination of its utility is needed.

Interestingly, the study by Gerritse et al[14] was undertaken in the Netherlands, where insertions are performed by physicians based in the prehospital setting. Whether similar results are found in non-physician-based prehospital care systems in other countries, such as Australia, the United States, or the United Kingdom, remains to be seen. In terms of the user satisfaction ratings in that study, the potential for bias must be considered as

representatives from the manufacturer of the device facilitated the instructions on its usage.

Hubble and Trigg,[12] who studied IO insertions by inexperienced paramedic students, argue that the teaching and learning process involved in successful IO insertion is relatively straightforward, suggesting that the procedure might be extended to use by intermediate-level paramedics.

While the majority of articles reviewed noted that intraosseous access (regardless of technique) offers a safe and simple method for gaining access to the patients' circulation, none of the studies clarify which device may be most appropriate for Australian paramedics to use in the prehospital setting. Overall, one IO device does not clearly appear to be better clinically. This suggests the need for cost-benefit analysis and financial feasibility studies.

Conclusions

In most Australian states, manual insertion of an intraosseous needle is the technique used by intensive care paramedics; however, the literature suggests that semiautomatic devices may be more effective. Further research, including cost-benefit analysis, is required at a national level to examine skill acquisition and decay, and whether other devices offer clinically relevant differences.

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